DEVELOPMENT OF A TELEOPERATED VEHIC

by

BHAGIRATHSINH N GOHIL

DEPARTMENT OF MECHANICAL ENGINEERING

INDIAN INSTITUTE OF TECHNOLOGY KANPUR

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DEVELOPMENT OF A TELEOPERATED VEHICLE

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BHAGIRATHSINH N GOHIL

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Dedicated to

My Parents and all the people
in manufacturing Science Lab.

CERTIFICATE

This is to certify that the thesis entitled, "DEVELOPMENT OF A TELEOPERATED VEHICLE" by Mr. Bhagirathsinh N. Gohil has been carried out under our supervision and has not been submitted elsewhere for a degree.

(Dr. A. Ghosh)
Professor

(Dr. A.K. Mallik)
Professor

Department of Mechanical Engineering
Indian Institute of Technology Kanpur

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CONTENTS

NOMENCLATURE

ω_1 = Angular velocity of driving motor

ω_2 = Angular velocity of steering motor

r = Wheel radius

R = Radius of circular path of wheel centres

R_p = Radius of circular path of the vehicle

V_p = Linear velocity of the vehicle

C = Centre to centre distance between the motor shaft and the driving shaft

d_1 = Pitch cone diameter of the gear

d_2 = Pitch cone diameter of the pinion

m = Module of the gear

δ_1 = Pitch cone angle of gear

δ_2 = Pitch cone angle of pinion

R_1 = Cone distance.

LIST OF FIGURES

ABSTRACT

The objective of the present work is to design and fabricate a teleoperated vehicle which can act as the base of a mobile Robot. Accordingly, a three wheeled vehicle is designed and constructed. All the wheels are driven and steered simultaneously. Separate motors and controls are provided for driving and steering. The control system can be operated either manually or through a programmed microprocessor. The vehicle is designed to take any radius of path-curvature. The fabricated vehicle is demonstrated to move along various prescribed paths through programmed control.

CHAPTER 1

INTRODUCTION

1.1 Introduction

The use of the robots in various sectors is increasing day by day as they can replace humanbeings in hazardous and monotonous jobs, as well as, higher precision, accuracy, repeatability and speed can be achieved.

At present most of the robots in use are of stationary type, i.e. their base remain fixed to the ground. Such robots are capable of working within a fixed work space which depends on the size and configuration of the robots. Such robots can work satisfactorily so long as the situation does not demand continuous change in the position of working. However, there are certain areas of application where the work-space of the robot is not known in advance, in such cases it is imperative that robot changes its position in order to perform the job. The application of robots in nuclear establishments, under-water, deep mines etc. often demands that the robot moves bodily to cover a much wider workspace. Such robots where the base of the robot moves are called mobile robots [1,2].

1.2 Mobile Robots and Teleoperated Vehicles

Mobility or locomotion required in a mobile robot can be achieved in two ways namely legged locomotion and wheeled

locomotion [3]. Design and construction of legged locomotion which are essential for uneven terrain are quite involved and expensive [4,9] . For applications on even terrain, like factory floors, wheeled locomotion, which is simpler, is sufficient. In wheeled locomotion, as the name suggests, wheels are used to achieve the desired motion of the robot, when wheeled locomotion is used and when the robot has to change level, at that time slope can be provided instead of staircase [5].

For wheeled robots the motion of the robot can be controlled in three possible ways. For a decided path one possible method is to use underground wires or floor paints along the given path. Corresponding sensors are mounted on the robot which pick up signals and guide the robot along that path [6,7] . This method involves more hardware and so is not very flexible as it required change of network of wires or repainting the floor for changing the path. The second method consists of writing a program to control the motion of the wheels in order that the robot moves along a certain path and reaches the destination. Both open loop and closed loop control systems can be used depending on the situation. Here processors get the signals from the program and actuate the actuators accordingly so that the desired path is executed. In this mode, with the help of sensors, obstacles can be sensed and avoided, by altering the path of vehicle, through an appropriate algorithm [8].

In this approach, for generating a new path no change in the hardware is necessary, the only requirement is to write a new program. The third way to control the motion of a robot is by teleoperation. In this mode a human operator controls the motion of the robot from a distance. The operator can view the robot either directly or on a screen and can guide the robot to the destination by avoiding obstacle, if any, on the way. In this case no additional hardware or software is required for changing the path as the operator is controlling the motion directly through the interface.

1.3 Objective and Scope of the Present Work

The objective of the present work is to develop a vehicle which can act as the platform of a mobile robot. The motion of this platform is to be controlled in two ways namely, manual teleoperation and programmed modes. A controller using digital circuit is developed for manual operation mode and an 8085 microprocessor kit is used for programming the motion. For taking various paths it is often required to divide the total length into a number of segments. Accuracy of tracking various segments is better with smaller radius of turning. In the present model the minimum radius of curvature is kept at zero. The entire operation is carried out in an open loop control scheme.

The scope of the work is limited to simple paths only. No sensors for sensing the obstacles are mounted and so there can not be any dynamic generation of path. The vehicle is not controlled by the radio signals and so the zone is limited by the length and the entangling of the wires. The model is demonstrated for 3 different paths in the programmed mode.

CHAPTER 2

KINEMATICS, MECHANICAL DESIGN AND FABRICATION

2.1 Introduction

The proposed design is for a three-wheeled vehicle with wheels placed symmetrically at 120° on a circle. All the three wheels are driven simultaneously by a motor placed at the centre of the platform to give uniform drive. While turning all the wheels are steered simultaneously by a second motor. Because of simultaneous steering the minimum radius of turning is zero.

In the present chapter first the kinematics of the vehicle is described. This explains how the change in the path of the vehicle results when either or both of the driving and the steering motors rotate. This is followed by the details of mechanical design of the vehicle. Some typical arrangements of the components which are important at the fabrication stage are also noted.

2.2 Kinematics of a Three Wheeled Vehicle

As already mentioned, the three wheels of the vehicle are placed on a circle at 120° with each other. Figure 2.1 shows one such wheel and also explains how it is connected to the driving motor. The other two wheels are connected to the same motor in identical fashion. Thus, all the three wheels get the same driving (either forward or reverse)

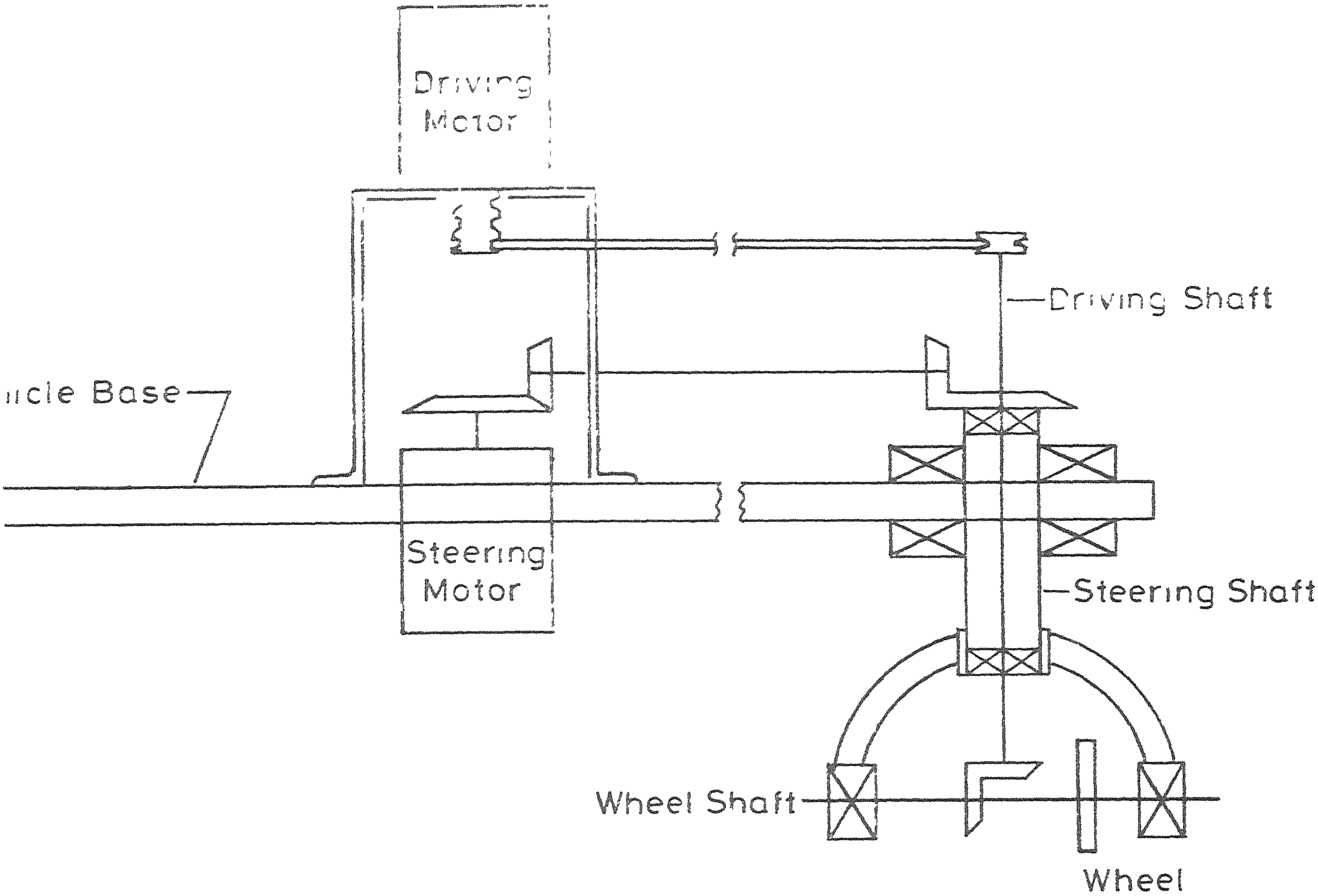


Fig. 2.1 Schematic diagram of the vehicle.

motion simultaneously. The steering motor is also shown in the same figure. It should be noted that the steering shaft acts as the housing for both the driving and the wheel shafts. Again the same steering motor is connected to all the three wheels in an identical fashion.

The driving shafts are connected to the driving motor by a direct belt-pulley drive with unity angular velocity ratio. The wheel shafts are connected to the driving shafts again with unity angular velocity ratio through bevel gearing. Hence if the angular velocity of the driving motor is ω_1, the linear velocity of the centre of the wheels and that of the platform is given by $\omega_1 r$ where r is the radius of the wheels.

As indicated in Figure 2.1, the wheels are offset from the driving shaft axis by a distance r equal to the wheel radius [5]. With this eccentricity, it is obvious that if only the steering motor is given one rotation while the driving motor is kept stationary then all the wheels come back to their original position without any movement of the platform. Of course each wheels rolls one full circle around its corresponding driving shaft axis and at the same time completes one revolution about its own axis. Thus the wheels come back to their original location and the orientation.

For any arbitrary amount of rotation of the steering motor with the driving motor stationary, all the wheels change

their position and orientation in identical manner while the vehicle base neither cnanges its position nor its orientation.

Let us now consider the movement of the vehicle when both the driving and the steering motors are rotated simultaneously at different speeds. For this we consider only one of the wheels as all the wheels have identical motion.

Let the angular velocity of the driving motor be ω_1 and that of the steering motor be ω_2. Then the velocity of the centre of the wheel due to the driving motor is $\omega_1 r$ while that due to the steering motor is $\omega_2 r$. As both these velocities at any instant are in the same direction, the magnitude of the resultant linear velocity of the wheel centr is $(\omega_1 + \omega_2)r$. The direction of this velocity is given by the direction of the vector $\vec{\omega}_2 \times \vec{r}$ where vector $\vec{r}$ represents the eccentricity of the wheel. For constant value of ω_2 the path traversed by all the wheel centres will be circles of radius R(say), when

$$\omega_2 R = (\omega_1 + \omega_2) r$$

or

$$R = \frac{\omega_1}{\omega_2} r + r$$

As explained in Figures 2.2(a) and 2.2(b), for circul- paths of the wheel centres of radius R, the vehicle base moves

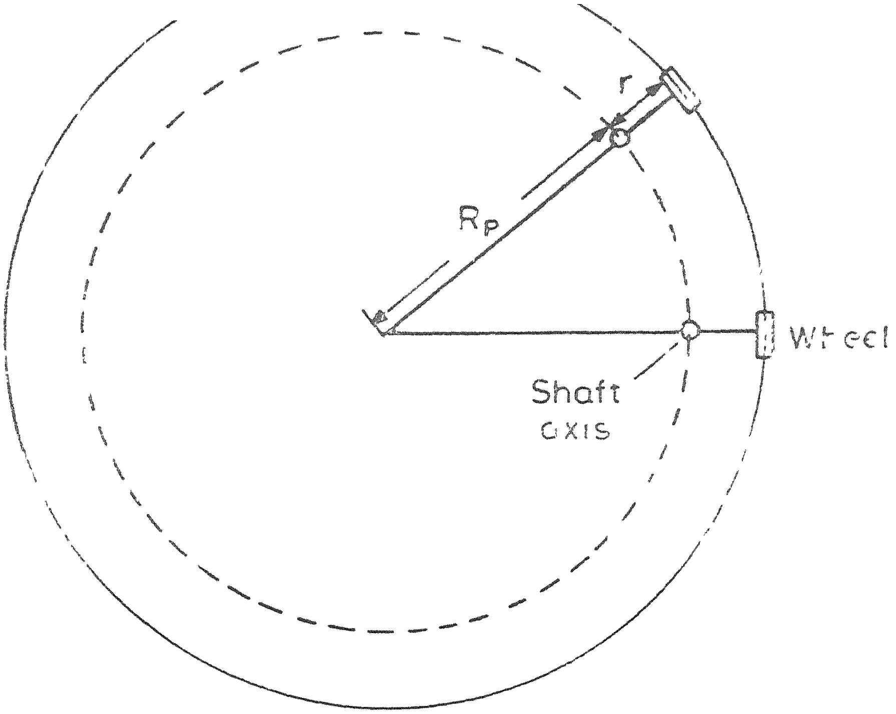


Fig 2 2(a)

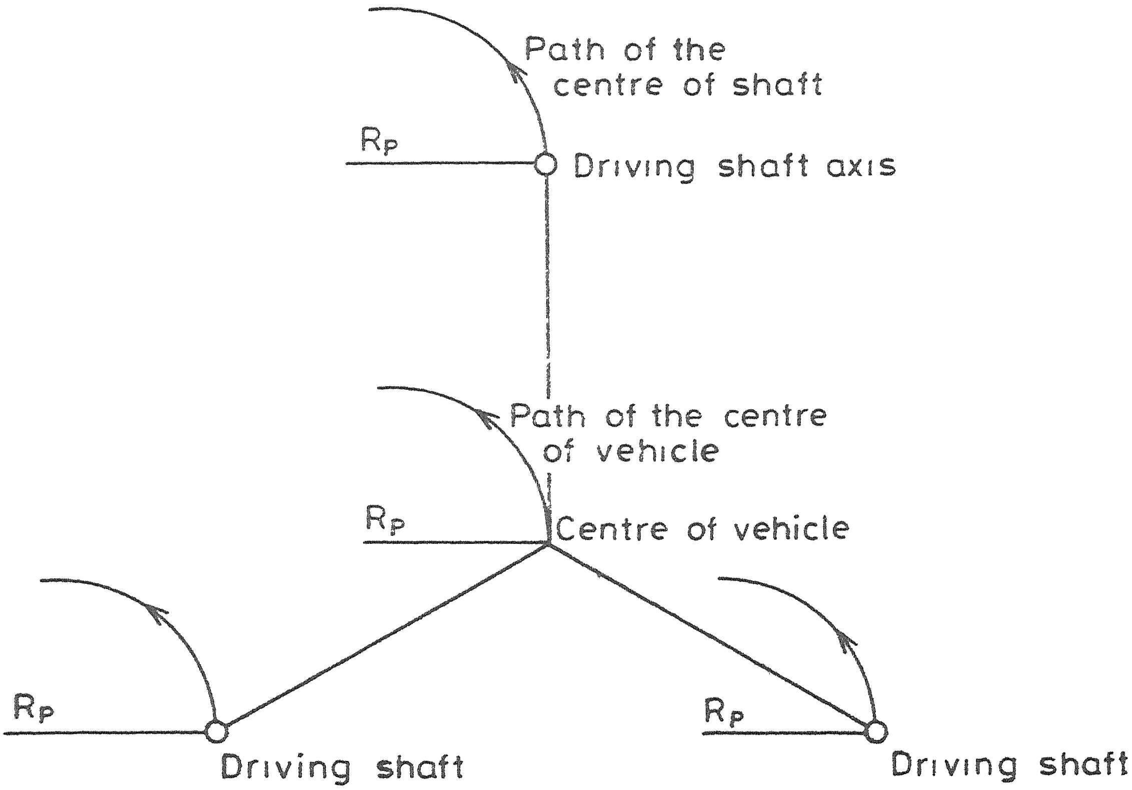


Fig. 2.2(b) Path of the vehicle when both the motors rotate.

in a circle of radius

$$R-r = \frac{\omega_1}{\omega_2} r .$$

So finally the linear velocity of the platform is obtained as

$$V_P = (\omega_1 + \omega_2)r \qquad (2.1)$$

along a circle of radius

$$R_P = \frac{\omega_1}{\omega_2} r . \qquad (2.2)$$

By choosing different values of ω_1 and ω_2 the platfor can be moved at different velocities along circles of varying radii. It is obvious that with the steering motor stationary i.e. $\omega_2 = 0$, the platform moves along a straight line ($R \to \infty$). In either case the orientation of the vehicle remains unchanged.

2.3 Mechanical Design of the Vehicle

To determine the torque required to drive and steer the vehicle, all the calculations are carried out by assuming the mass of the vehicle to be 30 Kg. Few simplifications are made by considering the worst case and so the actual torque requirement is less than that determined from this calculation. In order to determine the torque, traction required to drive the vehicle is to be found. Traction in turn depends on the

condition of surface on which the vehicle is supposed to be driven. Empirical data are available in the hand book which are used for car driving. These data are assumed for the present case.

Data given in the hand book [10] .

	Kind of Surface	Traction in lb/1000lb	Traction in N/kg
(1)	Hard smooth asphalt	11	.10791
(2)	Wood paving	13	.12753
(3)	Good macadem	17	.16677
(4)	Bad macadem	22-45	.216-.44
(5)	Cobbles	26	.255
(6)	Bad cobbles	upto 110	upto 1.0791.

From the above data the condition of good macadem is used for the present case. The actual surface will be better and hence the torque required will be less than that computed.

For present case the total traction required

$$= 0.16677 \times 30 = 5.0 \text{ Nt.}$$

So total torque required for driving

$$= \text{traction} \times r$$

$$= 5 \times \frac{3.25}{100} = 0.1626 \text{ Nt-m.}$$

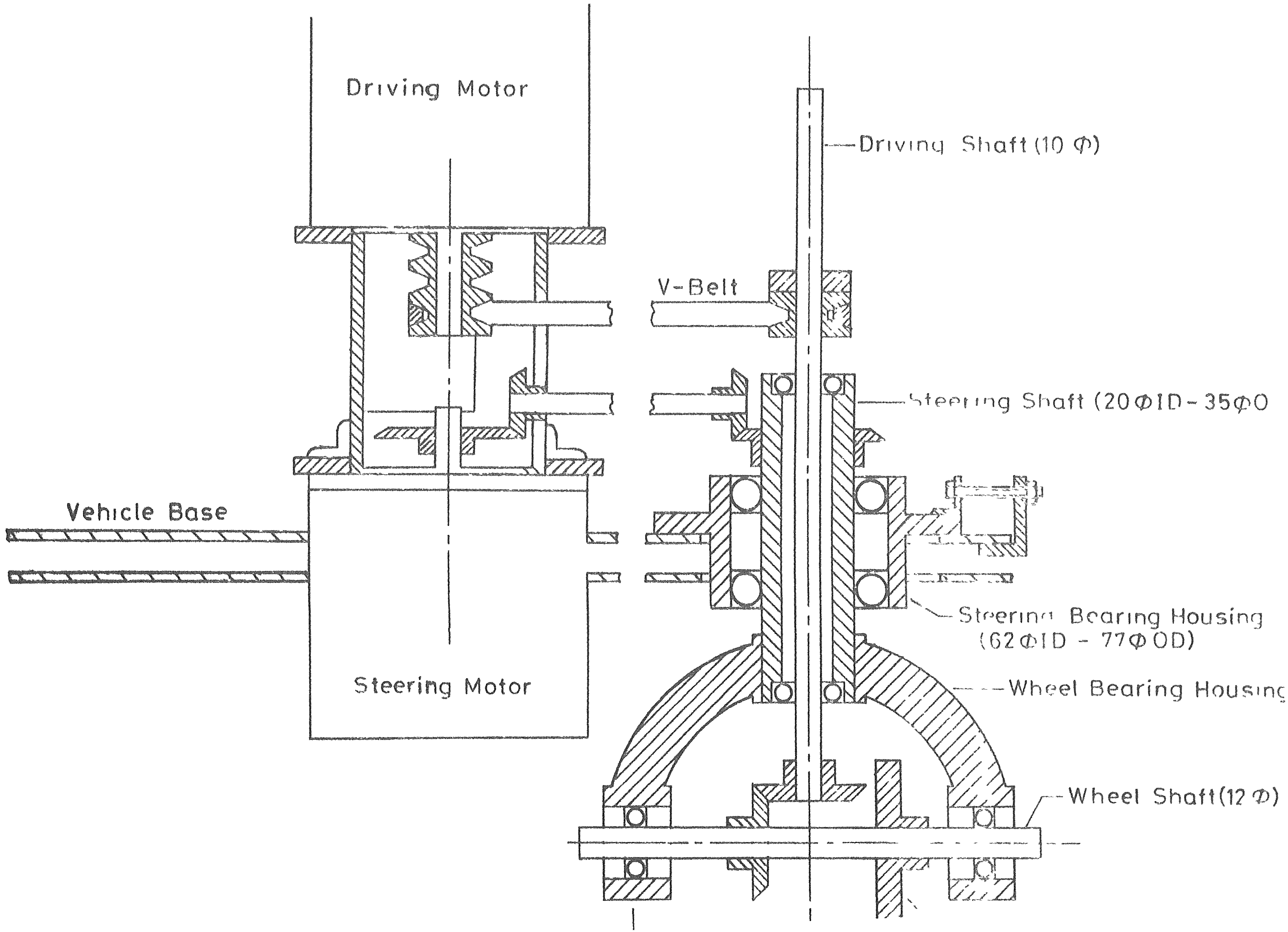
The torque required for steering is equal to that for driving, as in both cases the wheels are rolling.

In addition to this there will be inertia torque acting which is very difficult to determine. However, depending on the desired acceleration this inertia torque can be much more than the torque required for traction. Moreover, friction torques at various places like belts, bearings etc. also add to the requirement. From the list of stepper motors available, motor with 1.96 Nt-m torque rating is chosen to suffice for any future addition on the vehicle.

Details of Components:

Each wheel assembly has three shafts namely, the wheel shaft, the driving shaft and the steering shaft enclosing the driving shaft (Figure 2.3). The driving shaft is taken of 10 mm diameter and corresponding bearing available is of size 10 mm-26 mm internal-external diameter [11]. The steering shaft encloses the driving shaft and will support it at ends with bearings. This shaft is supported on the vehicle base with two bearings and so according to the bearing size the outer diameter of the steering shaft is kept at 35 mm. The wheel shaft is kept of 12 mm diameter and is supported at bearing housing by corresponding bearings for the shaft size.

From the driving motor to the driving shaft the motion is transferred by using V belt of 450 mm length and 9 mm


Driving Motor
Driving Shaft (10 Φ)
V-Belt
Steering Shaft (20ΦID - 35Φ0
Vehicle Base
Steering Bearing Housing
(62ΦID - 77Φ OD)
Steering Motor
Wheel Bearing Housing
Wheel Shaft (12 Φ)

thickness. Pulleys used are of 30 mm diameter at both motor end and driving shaft and to keep the velocity ratio as unity. From the driving shaft, the motion is transferred to the wheel shaft through a pair of bevel gears. Gears are made of aluminium. The velocity ratio is kept one and gear PCD is taken as 46 mm and module 2 mm.

Initially it was decided to use V belts for transmitting motion from the steering motor to the steering shaft. However, belts were not transmitting the motion effectively and so it was decided to use bevel gears for transmitting this motion as well. Two sets of gears are used to transmit the motion with overall velocity ratio unity [12]. From the steering shaft, the motion is directly conveyed to the bearing housing. The bearing housing is of circular shape (Figure 2.5) and the wheel and the bevel gears are enclosed in the space between supporting bearings in the housing.

Calculations are presented in Appendix 1 for detailed design of gears and belts.

2.4 Mechanical Fabrication

The vehicle base is made of Aluminium sheets. Two 50 cm x 50 cm aluminium sheets of $\frac{1}{8}$" ($\simeq$ 3.2 mm) thickness are used for this purpose. Both the sheets are separated by 12.5 mm thick spacers. The spacers give additional strength to the base and use of the sheets makes cutting of slots in the

base easier.

The steering motor is mounted at the centre of the base. Bearing housings supporting steering shafts are mounted 120° apart. Oval shaped slots are cut for adjusting tension of the belts. The entire assembly of steering bearing housing to the wheel is made adjustable so as to slide inward or outward. Bolt and nut are used for this adjustment which in turn adjust the tension in the belt. Once the tension is adjusted then the steering bearing housing is tightened with the base by four, sets of nuts and bolts (Figures 2.4(a) and 2.4(b)).

The bearing housings of wheel bearings are made of Aluminium castings and holes for the wheel shaft bearings and steering shafts are bored at 90° with each other (Figure 2.5).

The driving motor is also placed at the centre of the base and on the top of the steering motor (Figure 2.6). Care is taken to align the shafts of the steering and the driving motors. The driving motor is supported on the steering motor by means of a hollow cylindrical piece having flat surfaces on either sides to fix with both the motors as well as the vehicle base. Three slots at 120°, are cut in the cylindrical piece to let the belts and shafts of the gears pass through them. This cylindrical piece together with the steering motor is connected to the base by

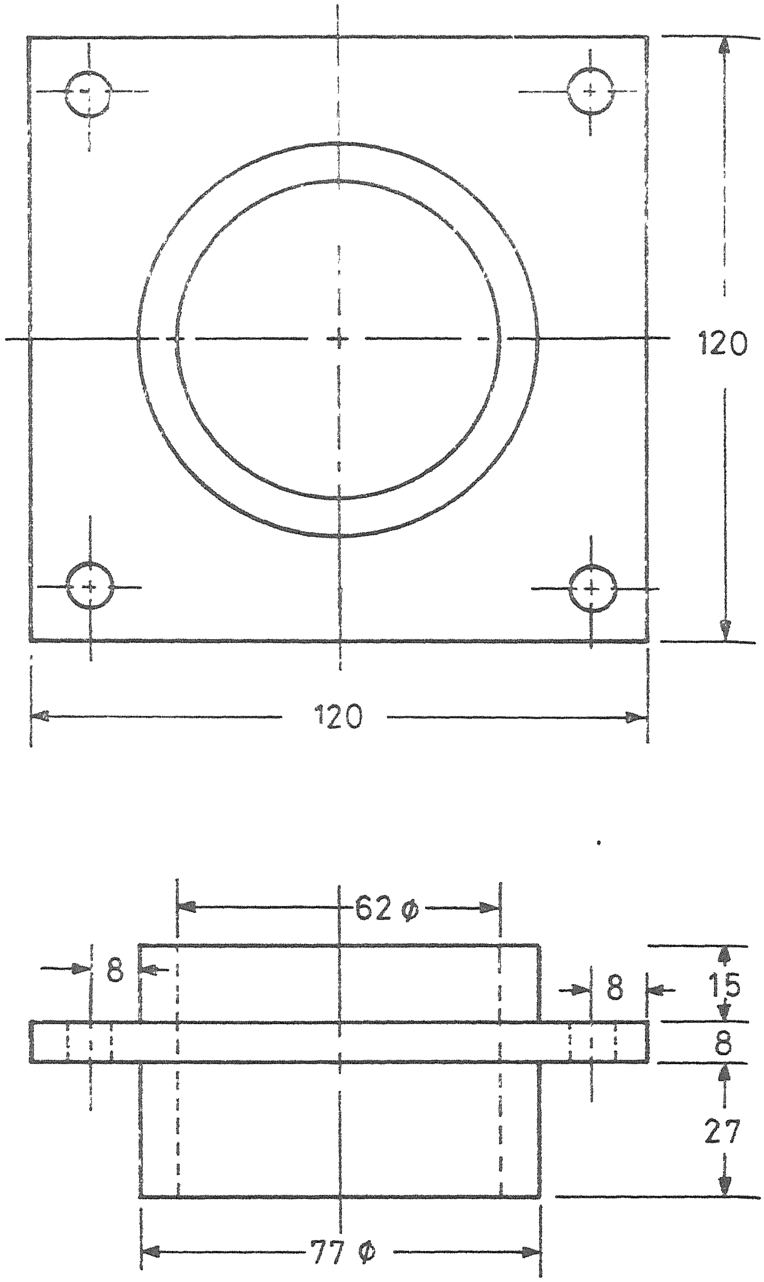


Fig. 2.4(a) Bearing housing for steering shaft

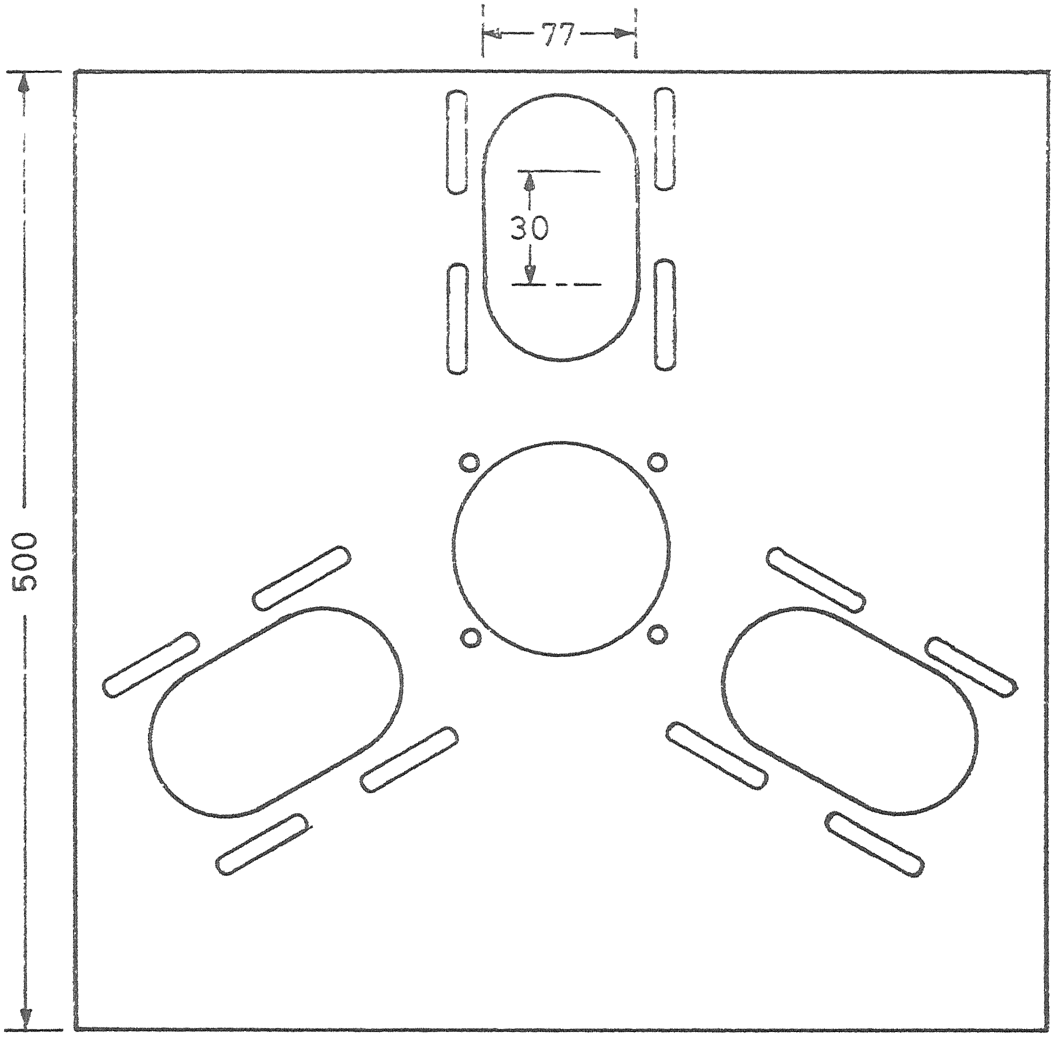


Fig. 2.4(b) Vehicle base.

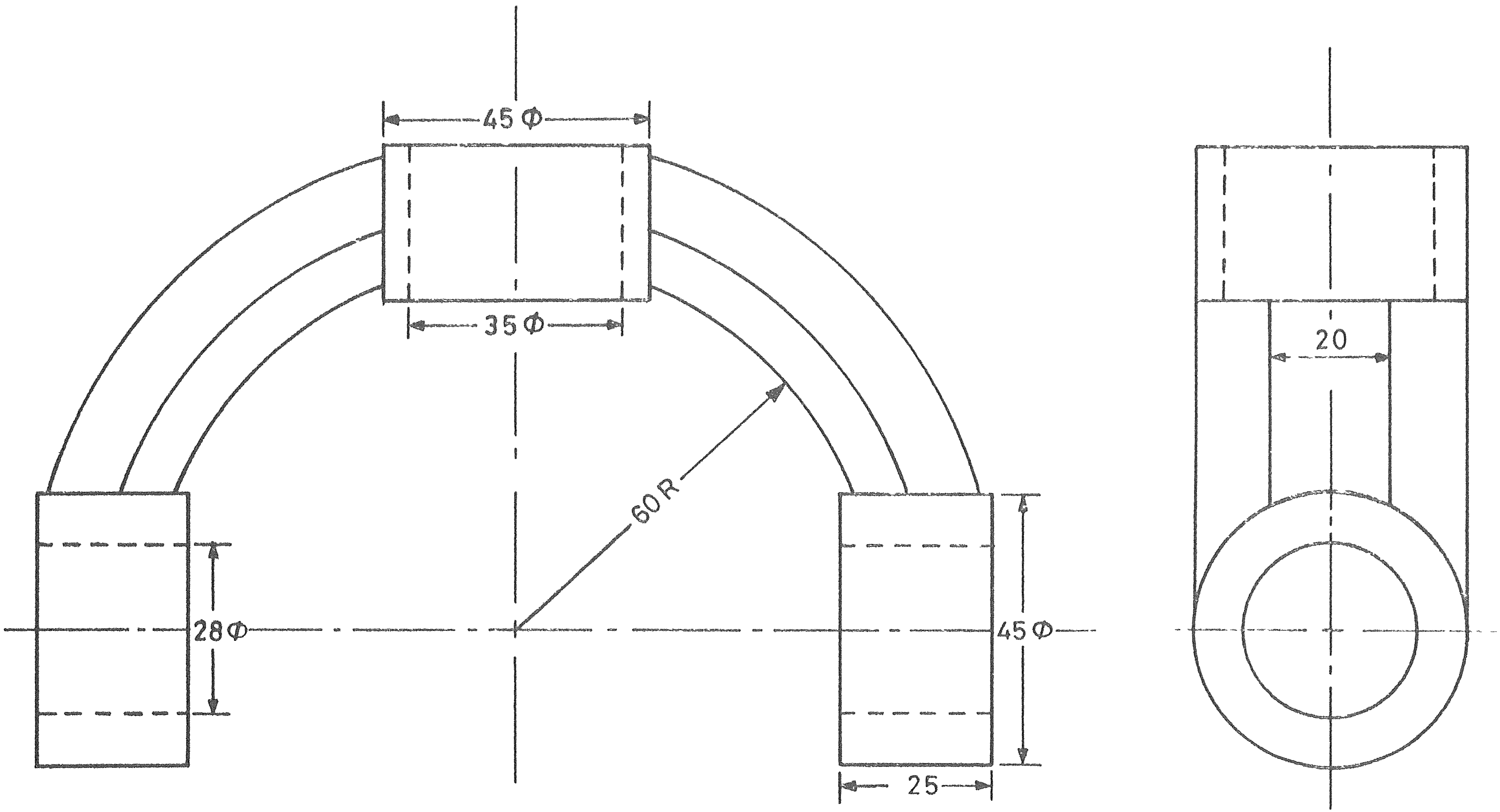


Fig. 2.5 Bearing housing of wheel shaft.

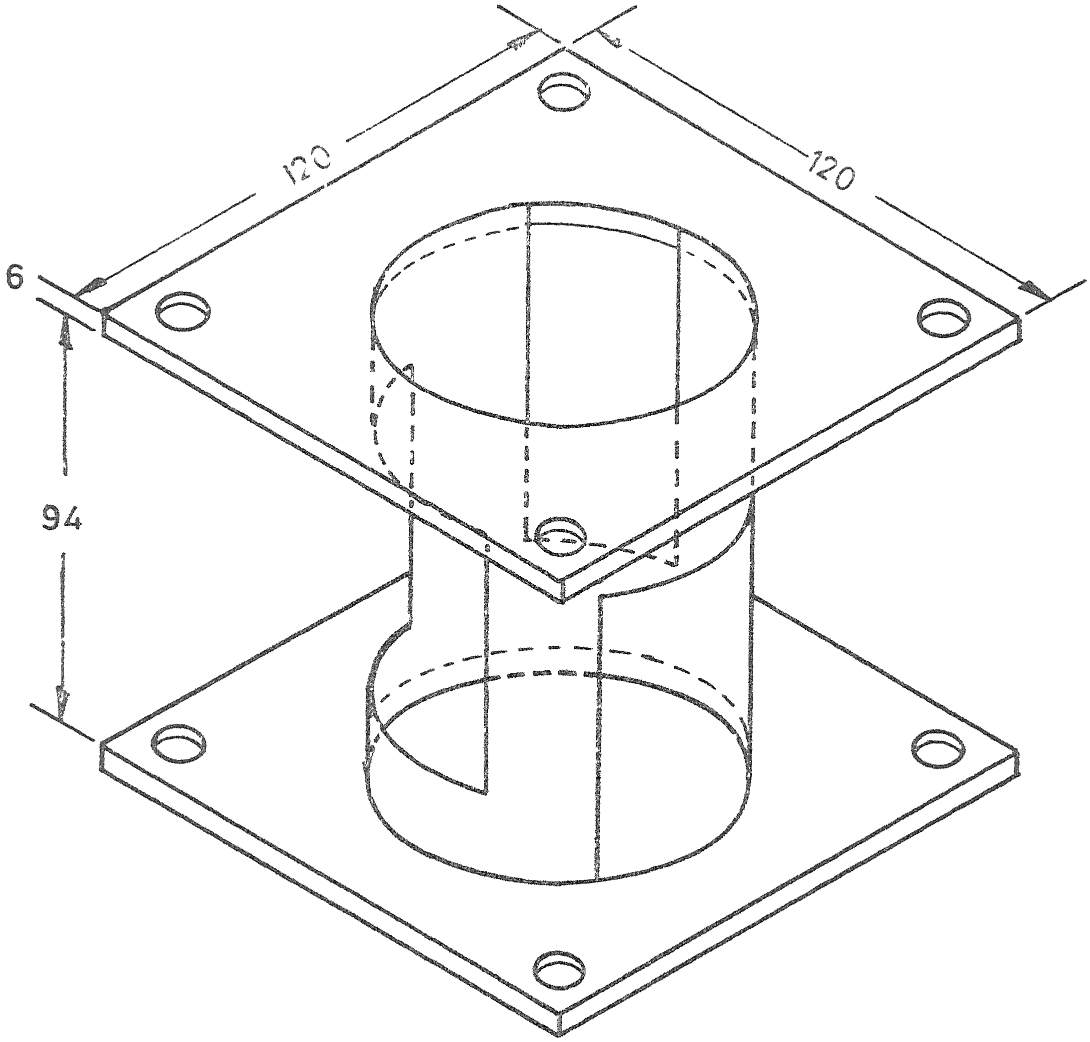


Fig. 2.6 Spacer between two motors

four bolts and is connected with the driving motor by four screws.

CHAPTER 3

DRIVE AND CONTROL CIRCUITS FOR VEHICLE MOTION

3.1 Introduction

In the vehicle stepper motors are used for giving both the driving and the steering motions. By controlling the speed and number of rotations of each motor, the effective motion of the vehicle can be easily controlled. As already mentioned, the vehicle motion is controlled in two modes, namely, manual and programmed modes. The present chapter describes the principle and method adopted for above modes and various circuits used to achieve this purpose. An algorithm for controlling the motion of both the motors simultaneously using a microprocessor is also included.

A stepper motor is an electromagnetic incremental actuator which converts digital pulse inputs to analog output shaft motion. The shaft of the motor rotates by 1.8°/pulse and thus has 200 steps/revolution. It has four windings which have to be energised, in correct sequence, in pairs. By reversing the sequence the motor rotates in the opposite direction. Following table gives the sequence for both rotations. The same sequence is repeated after every four steps [13,14,15] .

TABLE 3.1

Step No.	State of Phase				State of phase fo reverse direction			
	I	II	III	IV	I	II	III	I
1	1	0	0	1	1	0	0	
2	1	0	1	0	0	1	0	
3	0	1	1	0	0	1	1	[illegible]
4	0	1	0	1	1	0	1	[illegible]

3.2 Design of Control Circuit and Power Supply

In the present work initially stepper motors of 0.687 Nt-m torque capacity and rating of 12V, and .67 amp/phase were used. However, the torque supplied was found to be inadequate. So stepper motors of 1.96 Nt-m torque capacity and rating of 12V. and 1.25 amp/phase are used.

Power Supply:

Two 12V supplies for two motors and one 5V supply for the control circuit are used. All three supplies are housed in a single unit. Figure 3.1 shows the circuits used for these supplies. The 5V supply is also made variable for giving different voltages in the range 2-12 V. To get uniform voltage level the regulators 7805 and 7812 are used for 5V. and 12V. supplies respectively. Since each motor requires high current, power transistors 3055 are used in 12V. supplies. For 12V supplies capacitors of high values are used

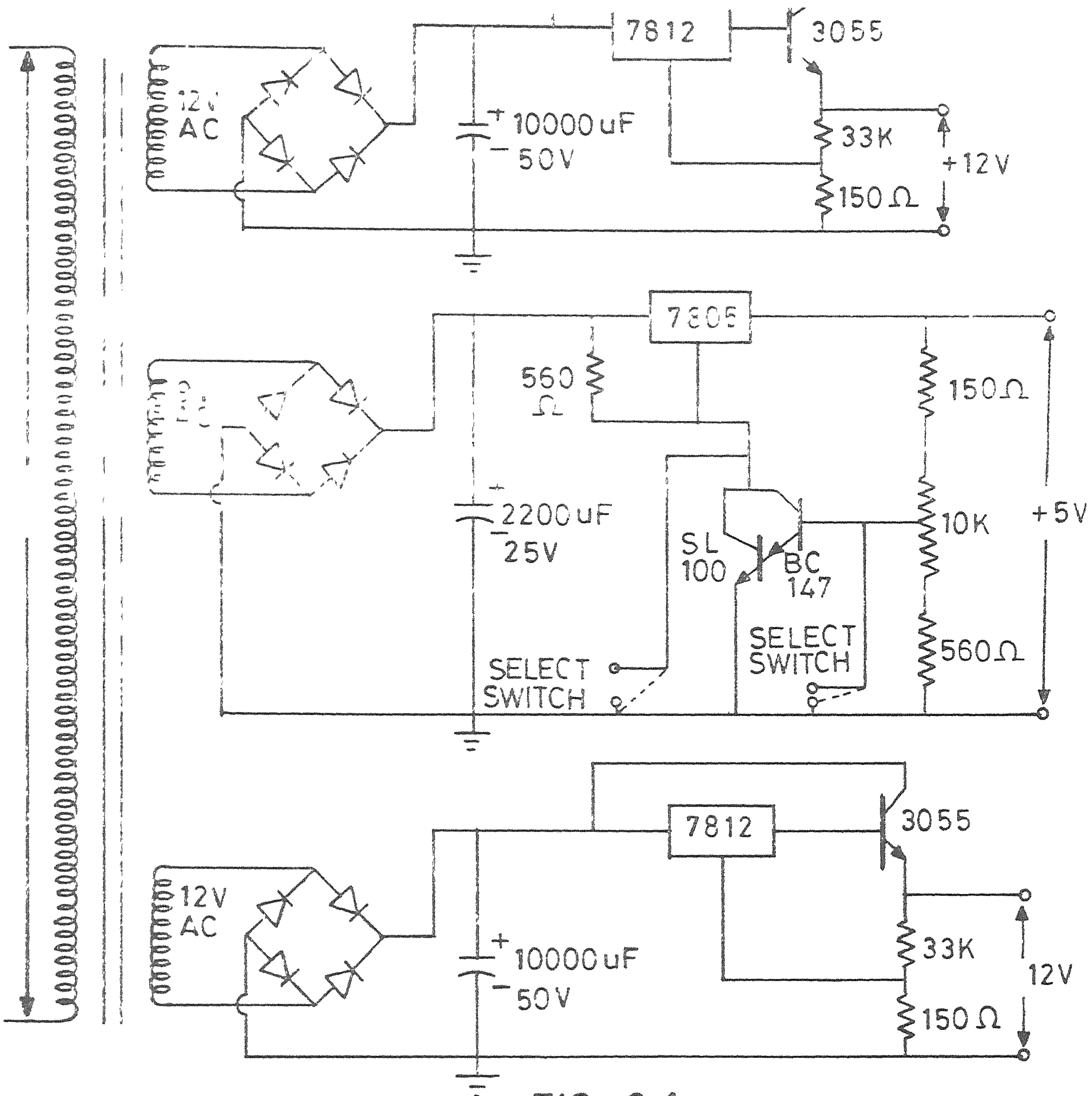


FIG. 3.1
Ckt diagram for power supply

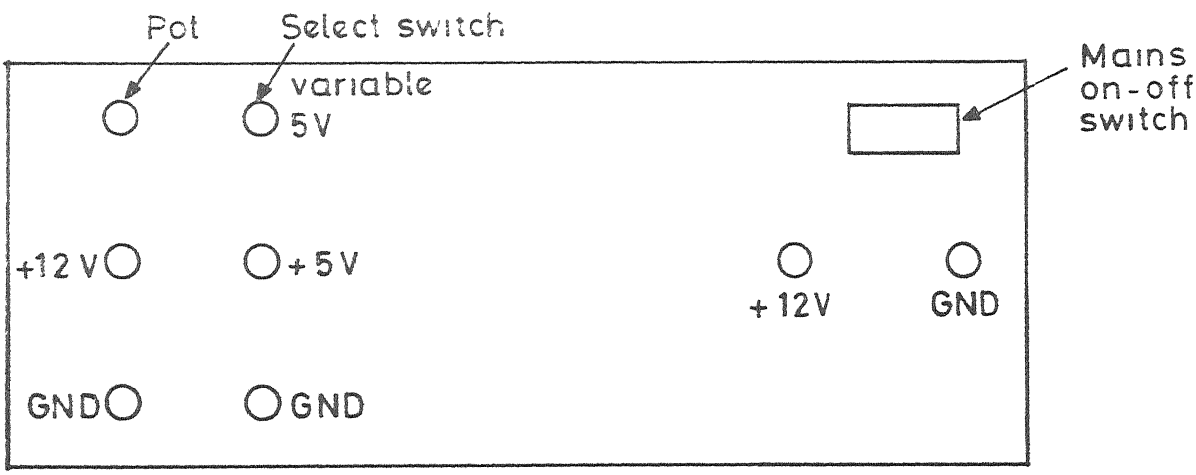


FIG. 3.2

to minimize the ripple. Figure 3.2 shows the front view of power supply giving details of layout of output sockets.

Control Circuit

Figure 3.3 is a block diagram of the control system used to control the motion of each stepper motor and hence of the vehicle. As seen from Figure 3.3, the control system has four distinct parts. First two parts, namely the manual controller and the microprocessor are supplying identical signals to the translator and the select switch position decides the input to the translator. The translator takes in these signals and gives four pulses in correct sequence to the stepper motor drive circuit which in turn provides the pulses in correct sequence to the motor. First let us explain the manual controller along with the translator. Thereafter, we take up the microprocessor part followed by the drive circuit.

Manual Controller and Translator

Two identical circuits for two motors are used and so only one is explained here. The speed of the stepper motor depends on the step rate or pulse frequency given by the manual controller while the direction is controlled by the direction signal given by the controller.

For generating clock pulses, hex schmitter is used [16]. This schmitter when connected with capacitor and resistance

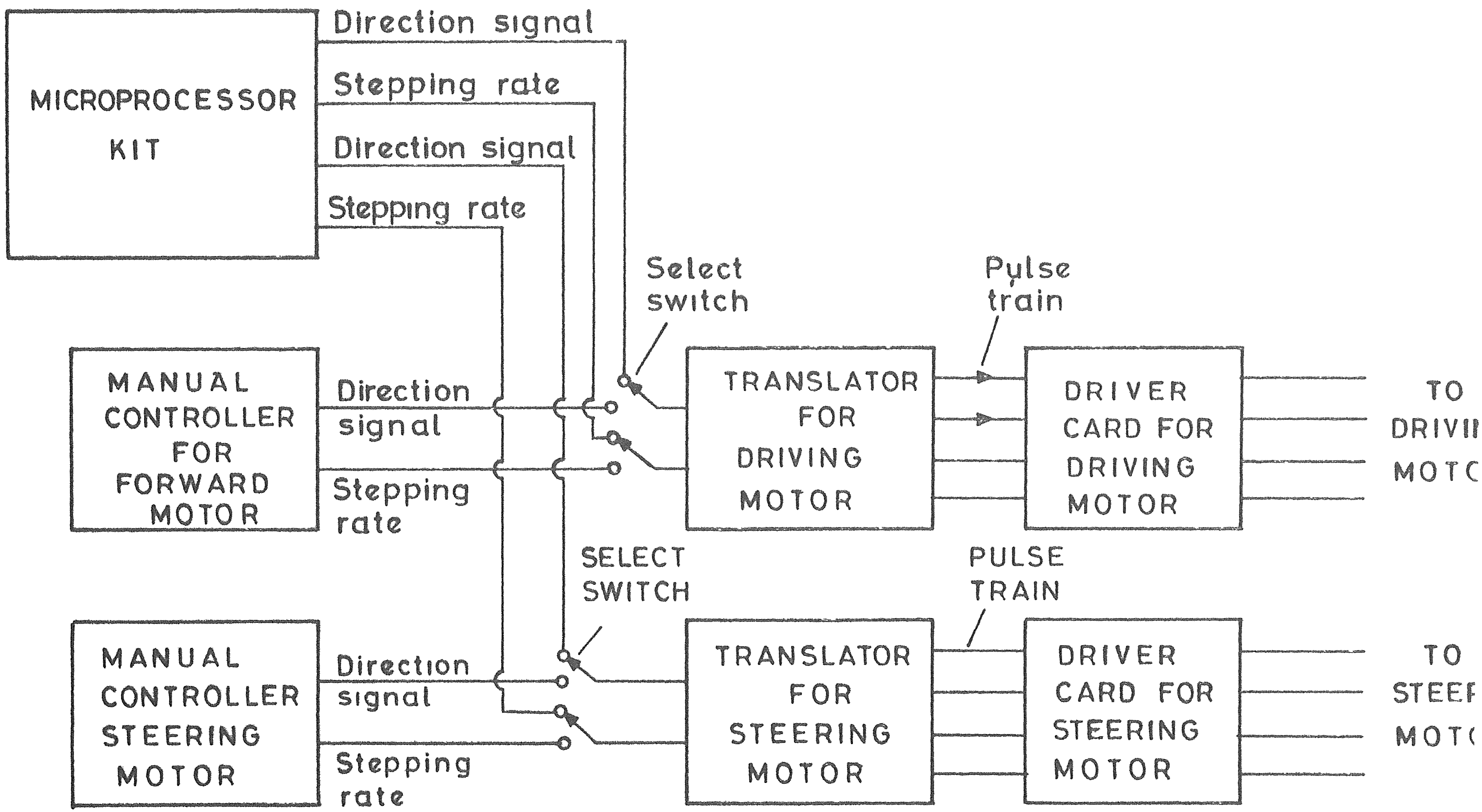


FIG. 3.3 BLOCK DIAGRAM OF CONTROL SCHEME

gives the oscillating signal (pulse) at the output. A potentiometer controls the frequency of this pulse and hence the speed of the motor. A D.P.D.T. switch along with a start latch and nand gate acts as ON-OFF switch for the motor motion by either allowing this pulse to go to the translator or by giving no pulse at the nand gate output. This pulse along with direction control bit now goes to the translator through the select switch. The translator converts this one pulse into four pulses of equal frequencies but with phase difference so that the correct sequence is maintained. It uses two exclusive or gates and two D flip-flops. Figure 3.4 is the circuit diagram of manual controller and translator. Two similar circuits are used to control motions of both the motors simultaneously. Using this controller the speed of the stepper motors can be varied from 3 RPM to 66 RPM.

Microprocessor Based Controller

In programming mode the signals to the translators of both the driving and steering motors come from the microprocessor. When the motion required demands rotation of both the motors the microprocessor provides two clock pulses and two direction signals. Thus the microprocessor gives four bit output to the translators. An 8085 microprocessor kit is used for this purpose. The algorithm used to generate the signals is shown in the form of a flow chart in Figure 3.5.

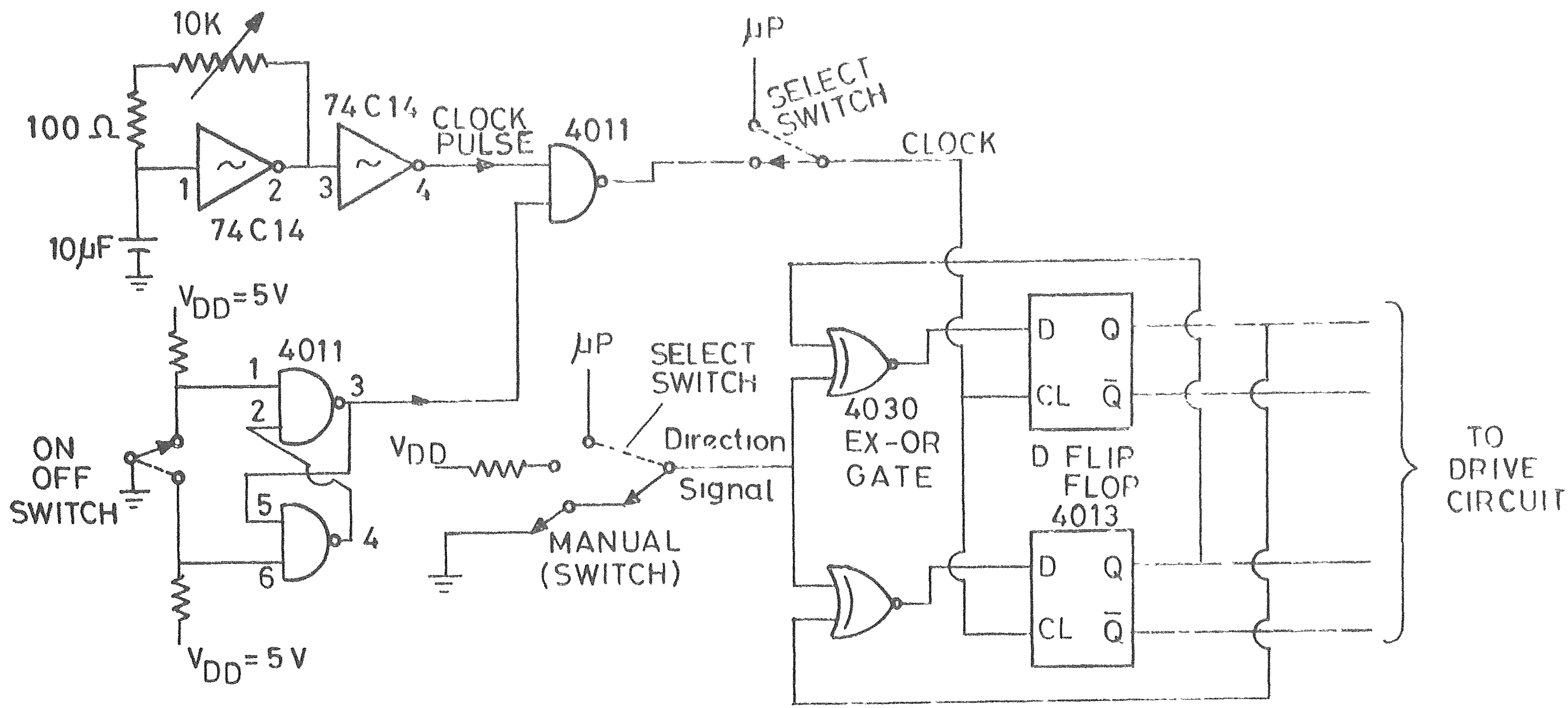


FIG. 3.4

MANUAL CONTROLLER & TRANSLATOR

A display routine is written which displays on-off status of both the motors and twice the steps of forward motor remained to be completed. This display routine acts as a delay routine. This routine is called N times where N is the delay value loaded. After every N times the count values of both the motors are reduced by one and when any of the count value becomes zero the clock bit of that motor is changed and the step value is reduced by one. This procedure is repeated until the step value reduces to zero. Thus the microprocessor controls the motion of both the motors simultaneously. The listing of this routine is given in Appendix 2. along with the listing of the program for different paths [17,18]. Count value of the motors are stored in one byte memory for each motor, this limits the ratio of speed of two motors to 256. This ratio can be increased by keeping more bytes for the count value.

3.3 Design of Drive Circuit

The sequence of pulse train output of the translator are of low level signals and can not drive the motor and so a drive circuit is used to drive the motor. The function of the drive circuit is to accept low level input logic signals in the form of a digital pulse train from the translator and control the sequence of the high current to the motor phases in order to produce the discrete angular motion. To turn a motor phase ON, a voltage signal is applied to BC 147

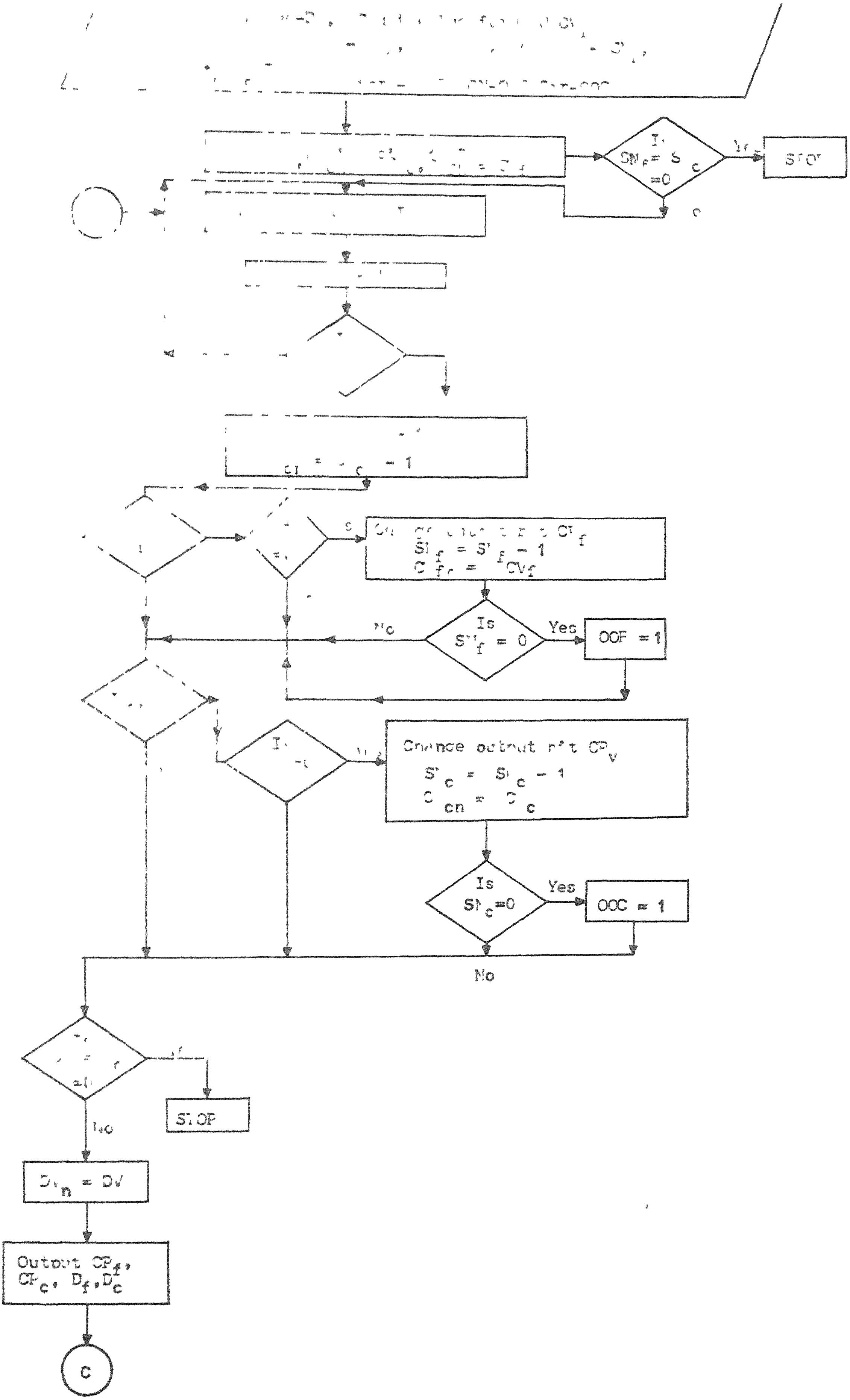


Figure 3.5 : Flow Chart for the Motion of the Vehicle

transistor to turn it ON. This, in sequence, turns ON [illegible] transistor and 3055 power transistor which completes the circuit and the current builds up through the motor phase. When the motor phase is turned OFF by changing the signal at BC-147 transistor base, all three transistors are turned OFF. At this time the current in the motor phase decays through the flyback diode and thus discharges the motor phase. By repeating this process we can get discrete angular motion of the motor shaft. Figure 3.6 shows this circuit. Figure 3.7 shows layout of PCB for this circuit.

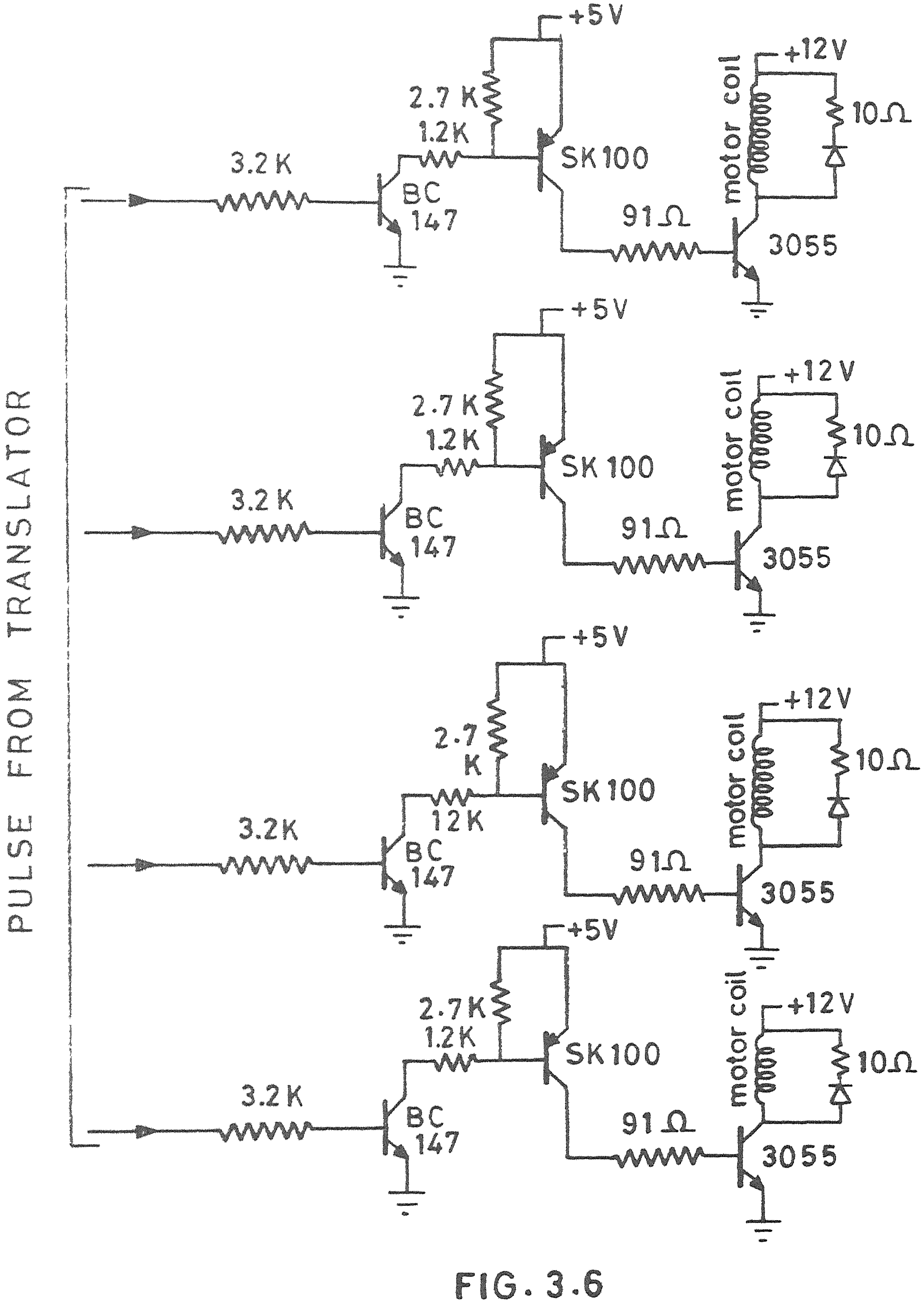


FIG. 3.6

DRIVE CIRCUIT FOR THE MOTOR

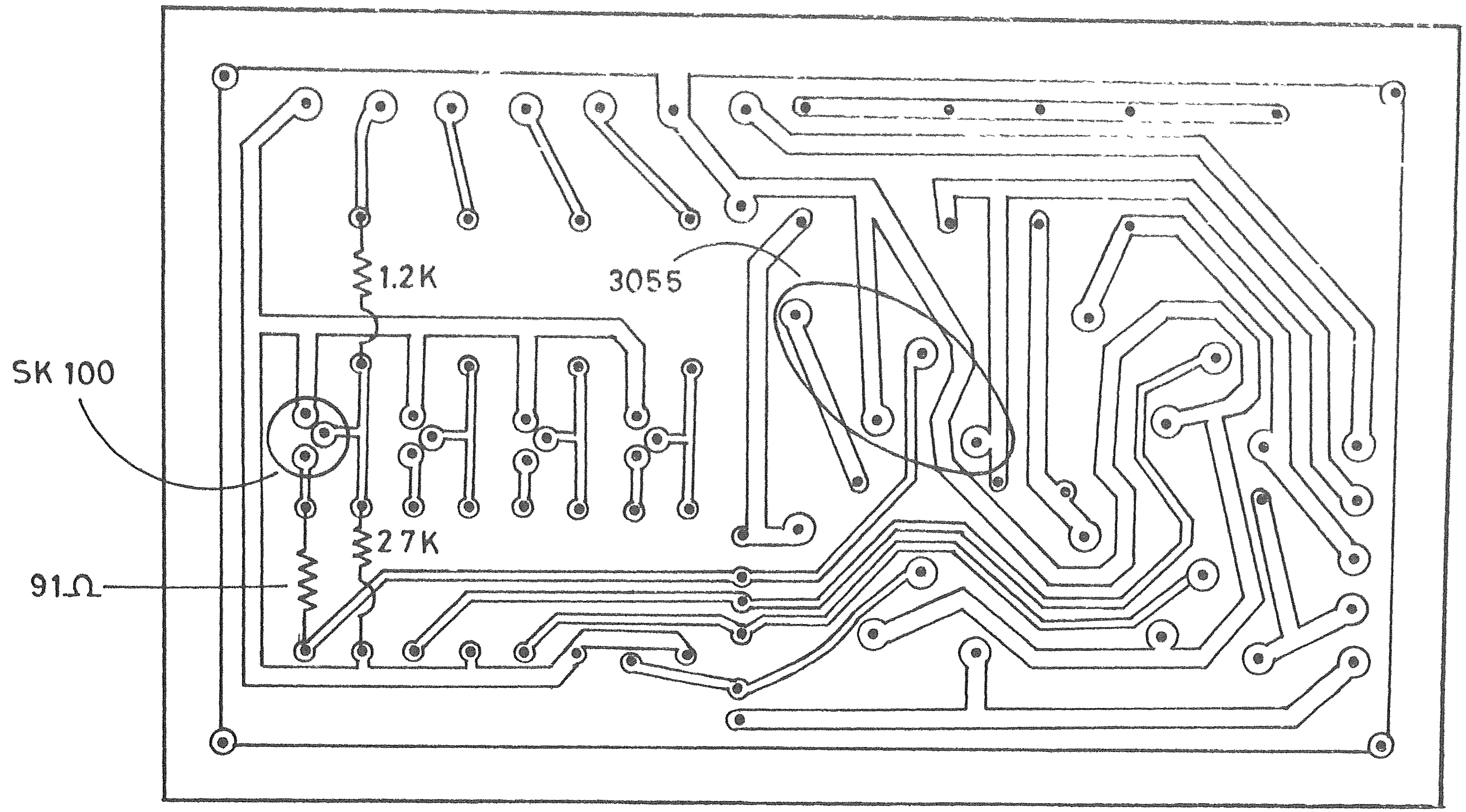


FIG. 3.7 PCB LAYOUT FOR DRIVE CIRCUIT

CHAPTER 4

RESULTS AND DISCUSSIONS

After completing the fabrication, the vehicle was operated and tested in both the manual and the programmed mode.

In the manual mode operation, in order to reach the destination by avoiding the obstacles, the path taken was divided into a number of segments of straight lines and circular arcs. Thus both the path traced and the position of the vehicle were closely monitored and verified.

In the programmed mode, the microprocessor kit was programmed to take different paths. Program was written for taking three different paths, namely, a straight line, a circular path and a figure of 8 path. The program listing for the above shapes is given in the Appendix_2. For moving along a figure of 8 path, the motion was carried out in eighteen steps. The vehicle motion was observed while tracing these paths.

While carrying out the experiments, it was found that the torque ratings of the motors specified by the maker are not correct. Torque of the motors fall rapidly with increasing the rotational speed. So all the experiments were carried out at low speed. In the manual mode, due to limitations put by the hardware, the speed ratio of the two motors was limited to 6.

It was found that the vehicle deviates a little [illegible] during the operation. The driving shafts were not rotating with same angular velocity due to difference in the effective radii of the pulley and some slipping of the belts. There was some relative motion between the steering shaft due to slight backlash in the gears. These factors caused deviation from the desired path. In the manual mode, the vehicle can reach a destination by controlling the path. However, since the operation was carried out in the open loop in the programmed mode, error could not be entirely eliminated.

This problem can be solved to a large extent by using all gear drive. In order to monitor the motion in programmed mode, feed back control scheme can be much more effective as the error can be compensated by the appropriate motion given by the software.

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APPENDIX 1

Calculations for Belt and Gear Drives

Calculations are presented here for belt and gear drives. Since load and torque acting is very less, emphasis is not given on strength aspect.

Belt Transmission:

From the motor to the driving shaft.

Diameter of pulleys $D_1 = D_2 = 30mm$

$\theta_1 = \theta_2 = \pi$ radian.

Length of belt at outer surface, $L = 45$ mm

Centre to centre distance between the pulleys

$$C = \frac{L - D}{2} = \frac{45 - x3}{2} = 177.78 \text{ mm.}$$

Gear Transmission

(a) From the driving shaft to the wheel shaft

Pitch cone diameter	$d_1 = 46$ mm
Module	$m = 2$ mm
Number of teeth	$= 23$
Pitch cone angle	$= 45°$
Face width	$= 8$ mm
Tip circle diameter	$= d + 2m \text{ Cos}$
	$= 46 + 2x2 \times \text{Cos } 45$
	$= 48.3$ mm.

Cone distance $R_1 = \frac{d}{2\sin}$

$= 32.52$

Addendum Angle $= \tan^{-1} \frac{m}{R}$

$= 3.5185°$

Dedendum Angle $= \tan^{-1} \frac{1.2m}{R}$

$= 4.22°.$

Blank cone Angle = Cone angle + Addendum Angle

$= 48.5°$

Root Angle = Cone Angle - Dedendum Angle

$= 40.78°$

(b) Between the steering motor and the steering shaft.

In order to keep velocity ratio unity, the gears on the motor and the steering shaft are identical. Gears placed at the end of the connecting shaft are also made identical. Calculation for one such pair is shown here.

Pitch cone diameter of gear d_1 = 57.5 mm

Pitch cone diameter of pinion d_2= 27.5 mm

Module m = 1.25 mm

Face width= 8 mm

Number of teeth on gear T_1 = 46

Number of teeth on pinion T_2 = 22

Pitch cone angle of pinion $\delta_2 = \tan^{-1} \frac{27.5}{57.5}$

$= 25.6°$

Pitch cone angle of the gear $\delta_1 = 90 - \delta_2$

$= 64.4°$

Tip circle diameter of the gear $= d_1 + 2m \cos \ {}_1$

$= 57.5+2x1.25xCos64.4$

$= 58.58$ mm

Cone distance $R_1 = \dfrac{d_1}{2 \sin \ {}_1} = 31.87$ mm

Addendum Angle $= \tan^{-1} \dfrac{m}{R}$

$= 2.246$

Dedendum Angle $= \tan^{-1} \dfrac{1.2m}{R}$

$= 2.695$

Blank cone angle for the gear $= 64.4 + 2.246$

$= 64.65°$

Root angle for the gear $= 64.4 - 2.7$

$= 61.7°$

Blank cone angle for the pinion $= 25.6 + 2.246$

$= 27.85°$

Root angle for the pinion $= 25.6 - 2.695$

$= 22.9°$

APPENDIX 2

LISTING OF PROGRAMME

ADDRESS	CODE	MNEMONIC	REMARKS
FE90	3E/80	RUN8 MVI A,80	Initialise 8255 in mode 0 with B as output port
FE92	D3 03	OUT 03	
FE94	2A 02 FF	LHLD FF02	COPY COUNT VALUES
FE97	22 OA FF	SHLD FFDA	
FE9A	AF	XRA A	Initialising 8279
FF9b	D3 19	OUT 19	
FE9d	21 04 FF	LXI H,FF04	Steps for F/W motor in D-E pair
FEA0	5E	MOV E,M	
FEA1	23	INX H	
FEA2	56	MOVE D,M	
FEA3	23	INX H	Steps for CR motor in B-C Pair
FEA4	4E	MOVE C,M	
FEA5	23	INX H	
FEA6	46	MOVE B,M	
FEA7	13	INX D	
FEA8	03	INX B	
FEA9	C3 00 FE	JMP START	JUMP TO MAIN ROUTINE

MAIN ROUTINE

ADDRESS	CODE	MNEMONIC	REMARKS
FE00	CD 00 FC	START:CALL DELAY	
FE03	21 09 FF	LXI H,FF09	
FE06	7E	MOV A,M	Get ON OFF Status

```
FE07        E6 03        ANI  03
[illegible] FE 03        CPI  03          If both motors to
                                          be off then return
FE0E        23           INX  H           If count of F/W
FE 0F       35           DCR  M           exhausted then call
                                          service routine
FE 10       CC 30 FE     CZ  F/W SRVC
FE 13       23           INX  H           If count of CR
FE 14       35           DCR  M           exhausted then
                                          call service routine
FE 15       CC 60 FE     CZ  RIV SRVC
FE 18       C3 00 FE     JMP  START
FE 20       C9           STOP : RET       Return to main
                                          program
```

SERVICE ROUTINE FOR FORWARD MOTOR

```
FE 30       1F           F/W SRVC:RAR     Check if ON OFF
                                          FLAG BIT IS 1
FE 31       DA 48 FE     JC  F/W  OFF
FE 34       3A 02 FF     LDA  FF02
FE 37       77           MOV  M,A
FE 38       1B           DCX  D
FE 39       7A           MOV  A,D         Check if number of
                                          steps for F/W
FE 3A       B3           ORA  E           motor exhausted
FE 3B       CA 50 FE     JZ  F/E FINISH   JUMP F/W FINISH
FE 3E       3A 08 FF     LDA  FF08        Flip the bit for
                                          F/W Clock and output
FE 41       EE 80        XRI  80          the result
FE 43       32 08 FF     STA  FF08
FE 46       D3 01        OUT  01
FE 48       C9           F/W OFF:RET
```

F/W FINISH:

FE 50	3A 09 FF	LDA, FF09	Change ON-OFF flag bit
FE 53	F6 01	ORI 01	
FE 55	32 09 FF	STA FF 09	
FE 58	C9	RET.	

SERVICE ROUTINE FOR STEERING MOTOR

FE 60	3A 09 FF	LDA FF09	Check ON-OFF flag bit
FE 63	1F	RAR	
FE 64	1F	RAR	
FE 65	DA 7C FE	JC:CR OFF	
FE 68	3A 03 FF	LDA FF03	Reload count
FE 6B	77	MOV M,A	
FE 6C	0B	DCX B	–
FE 6D	78	MOV A,B	Check if number of steps for cir mor exhausted
FE 6E	B1	ORA C	
FE 6F	CA 80 FE	JZ: CR FINISH	JUMP CR FINISH
FE 72	3A 08 FF	LDA FF08	FLIP the bit for CR clock and output the result
FE 75	EE 02	XRI 02	
FE 77	32 08 FF	STA FF08	
FE 7A	D3 01	OUT 01	
FE 7C	C9	CR OFF:RET	

CR FINISH :

FE 80	E5	PUSH H	Change ON-OFF Flag bit
FE 81	3A 09 FF	LDA FF09	
FE 84	21 OD FF	LX1 H , FFOD	
FE 87	B6	ORA M	

```
FE 88     32 09 FF     STA  FF09
FE 8B     E1           POP  H
FE 8C     C9           RET
```

DISPLAY ROUTINE

```
FC 00     C5           PUSH  BC
FC 01     2A 00 FF     LHLD  FF00
FC 04     44           MOV   B,H
FC 05     4D           MOV   C,L
FC 06     26 FC        MV1   H, FC
FC 08     3E 90        RPT: MVI  A,90
FC 0A     D3 19        OUT   19            Initialise 8279
FC CC     7A           MOV   A,D
FC 0D     E6, F0       AN1   F0
FC 0F     1F           RAR
FC 10     1F           RAR                 Display first bit
                                           of steps
FC 11     1F           RAR
FC 12     1F           RAR
FC 13     2E 60        MVI   L,60
FC 15     85           ADD L
FC 16     6F           MOV   L,A
FC 17     7E           MOV   A,M
FC 18     D3 18        OUT   18
FC 1A     7A           MOV   A,D           Display second bit
                                           of steps
FC 1B     E6 0F        AN1   0F
FC 1D     2E 60        MV1   L  60
FC 1F     85           ADD   L
```

```
FC 20    6F           MOV  L,A
FC 21    7E           MOV  A,M
FC 22    D3 18        OUT  18
FC 24    7B           MOV  A,E        DISPLAY Third bit
FC 25    E6 FO        AN1  FO
FC 27    1F           RAR
FC 28    1F           RAR
FC 29    1F           RAR
FC 2A    1F           RAR
FC 2B    2E 60        MVI  L,60
FC 2D    85           ADD  L
FC 2E    6F           MOV  L,A
FC 2F    7E           MOV  A,M
FC 30    D3 18        OUT  18
FC 32    7B           MOV  A,E        Display forth bit
FC 33    E6 OF        ANI  OF
FC 35    2E 60        MV1  L,60
FC 37    85           ADD  L
FC 38    6F           MOV  L,A
FC 39    7E           MOV  A,M
FC 3A    D3 18        OUT  18
FC 3C    3A 09 FF     LDA  FF09
FC 3F    6F           MOV  L,A
FC 40    1F           RAR
FC 41    1F           RAR
FC 42    3E 03        MV1  A,03       Display for
                                      direction
FC 44    D2 49 FC     JNC  zero
```

FC 47	3E 4F	MV1 A,9F	
FC 49	D3 18	Zero: OUT 18	
FC 4B	7D	MOV A,L	
FC 4C	1F	RAR	
FC 4D	3E 03	MV1 A,03	Display for direction
FC 4F	D2 54 FC	JNL ZR	
FC 52	3E 9F	MV1 A,9F	
FC 54	D3 18	ZR: OUT 18	
FC 56	0B	DCX B	
FC 57	78	MOV A,B	
FC 58	B1	ORA C	
FC 59	C2 08 FC	JNZ RPT	
FC 5C	C1	POP BC	
FC 5D	C9	RET	

TABLE FOR DISPLAY

		Display code for
FC 60	03	0
FC 61	9F	1
FC 62	25	2
FC 63	0D	3
FC 64	99	4
FC 65	49	5
FC 66	41	6
FC 67	1F	7
FC 68	01	8

FC 69	09	9
FC 6A	11	A
FC 6B	C1	B
FC 6C	63	C
FC 6D	85	D
FC 6E	61	E
FC 6F	71	F

PROGRAM

FD 00	31	60	FF	PROG: LXI SP FF60	
FD 03	21	70	00	LX1 H 0070	LOAD DELAY
FD 06	22	00	FF	SHLD FF00	
FD 09	CD	70	FC	CALL STR	CALL STR
FD 0C	CD	8A	FC	CALL CRC	CAL CRC
FD 0F	21	02	08	LX1 H 0802	LOAD COUNT VALUE
FD 12	22	02	FF	SHLD FF02	
FD 15	21	90	01	LX1H 01 90	LOAD STEPS F/W
FD 18	22	04	FF	SHLD FF04	
FD 1B	21	64	00	LX1 H 0064	LOAD STEPS CR
FD 1E	22	06	FF	SHLD FF06	
FD 21	CD	61	FD	CALL R1	
FD 24	00	00		NO OP	
FD 26	21	00	02	LXI H 0200	LOAd OUTPUT CONTROL
FD 29	22	08	FF	SHLD FF 08	
FD 2C	CD	90	FE	CALL RUN	

FD 2F	21 00 01	LX1 01 00	LOAD OUTPUT CONTROL
FD 32	22 08 FF	SHLDF F 08	
FD 35	CD 80 FD	CALL R3	
FD 38	3E 08	MV1 A, 08	LOAD COUNT VALUE
FD 3A	32 03 FF	STA FF 03	
FD 3D	CD 90 FD	CALL R4	
FD 40	CD 90 FD	CALL R4	
FD 43	CD 90 FD	CALL R4	
FD 46	CD 90 FD	CALL R4	
FD 49	21 FF 01	LX1 H 01 FF	LOAD OUTPUT CONTROL
FD 4C	22 08 FF	SHLD FF 08	
FD 4F	CD 80 FD	CALL R3	
FD 52	3E 08	MV1 A 08	LOAD COUNT VALUE
FD 54	32 03 FF	STA FF 03	
FD 57	CD 70 FD	CALL R2	
FD 5A	CD 61 FD	CALL R1	
FD 5D	CD 61 FD	CALL R1	
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ROUTINE

FD 61	21 64 00	LX1 H 0064	LOAD STEPS CR
FD 64	22 06 FF	SHLD FF06	
FD 67	21 00 02	LX1 H 0200	LOAD OUTPUT CONTROL
FD 6A	22 08 FF	SHLD FF08	
FD 6D	CD 90 EE	CALL: RUN	
FD 70	21 64 00	LX1 H 0064	
FD 73	22 06 FF	SHLD FF 06	

```
FD 76     21 00 00     LX1  00  00
FD 79     22 08 FF     SHLD  FF  08
FD 7C     CD 90 FE     CALL  RUN
FD 7F        C9           RET
FD 80     21 C8 00     LX1  H,00C8
FD 83     22 06 FF     SHLD  FF 06
FD 86     3E 01        MV1  A  01
FD 88     32 03 FF     STA  FF 03
FD 8B     CD 90 FE     CALL  RUN
FD 8E        C9        RET
FD 90     21 64 00     LX1  H, 00 64
FD 93     22 06 FF     SHLD  FF06
FD 96     21 FF 00     LX1  H, 00 FF
FD 99     22 08 FF     SHLD  FF 08
FD 9C     CD 90 FE     CALL RUN
FD 9F     21 FF 02     LX1  H, 02 FF
FD A2     22 08 FF     SHLD  FF 08
FD A5     CD 90 FE     CALL RUN
FD A8        C9           RET

FC 70     21 02 08     LX1  H,08 02
FC 73     22 02 FF     SHLD  FF 02
FC 76     21 BO 04     LX1  H, 04 BO
FC 79     22 04 FF     SHLD  FF 04
FC 7C     21 C8 00     LX1  H,00 C8
FC 7F     22 06 FF     SHLD  FF 06
FC 82     21 FF 02     LX1  H, 02 FF
```

```
FC 83        22  08  FF          SHLD  FF 08
FC 86        CD  90  FE          CALL  RUN
FC 89            C9                 RET

FC 8A        21  02  10          LXI  H, 1002
FC 8D        22  02  FF          SHLD  FF 02
FC 90        21  BO  04          LX1  H, 04 BO
FC 93        22  04  FF          SHLD  FF 04
FC 96        21  00  01          LX1  H, 01 00
FC 99        22  66  FF          SHLD  FF  06
FC 9C        21  FF  00          LX1  H, 00 FF
FC 9F        22  08  FF          SHLD  FF  08
FC A3        CD  90  FE          CALL RUN
FC A6            C9                 RET.
```